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THE INTERGLACIAL GORGES OF SIX MILE CREEK AT ITHACA, NEW YORK

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INTRODUCTION

The question of the complexity of the glacial period in central New York is still largely unsettled. It is conceded probably by all that the region has suffered more than a single ice invasion, but how many such invasions there were and how far the different invasions were separated from each other in time are problems as yet only partially solved.

The criteria for the identification of distinct glacial epochs which can be applied in a hilly region well within the southern limits of the ice, and even within the zone of active erosion by the latest Wisconsin ice sheet, are necessarily different from those which have been used so extensively and so successfully in the Mississippi Valley. Under the conditions prevailing in central New York one could not expect, for instance, to find drift sheets imbricated in the same manner as on the plains of the Mississippi near the limit of glaciation where the erosive power of the ice was doubtless slight and undirected and where deposition was the rule. Nor would it be possible to apply the common test of the relative erosion suffered by drift sheets of different ages, for, since the region in question lies within the great moraines of the Late Wisconsin epoch, any erosional features developed on earlier drift sheets would have been modified or destroyed by the Wisconsin ice. The hilly nature of the country, too, would tend to prevent the accumulation of till in even, continuous sheets and would lead to an irregular, patchy distribution of any remnants of earlier drift deposits. The meagerness, in this region, of the evidences from glacial deposits indicating multiple glaciation may be judged from the fact that, so far as the writer has been able to discover, only one investigator, Carney,[1] has definitely claimed to have found such deposits. Tarr[1] mentions two or three exposures of possible older drift near Ithaca, but believes that the evidence is inconclusive, and Gilbert[2] recognizes the possibility of two till sheets and the certainty of "an epoch of local till erosion by a glacier," but is led to no definite conclusions further than this.

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[1] "Pre-Wisconsin Drift in the Finger Lake Region of New York," *Jour. Geol.*, XV (1907), 571–85.

There is, however, another criterion of multiple glaciation for the application of which the Finger Lake valleys furnish ideal conditions. This criterion is the amount of work performed during interglacial intervals by streams whose normal profiles have been thrown out of harmony by glacial erosion or deposition; streams which must, therefore, resort to gorge-cutting in their endeavor to bring their beds back to normal grade.

A glacier moving along a valley tends to overdeepen it and to leave tributary valleys hanging. As soon as the ice withdraws, the streams in the hanging tributary valleys begin the work of bringing their beds down to the normal profile of equilibrium. In doing this they cut gorges in the lower ends of the hanging valleys. Given sufficient time after an ice invasion, the tributary streams would enter the main valley at grade through narrow, gorgelike valleys cut in the bottoms of the hanging valleys. These gorges, narrow at first, would, after their streams have reached grade, continue to widen in a normal manner under the influence of the ordinary weathering agencies combined with lateral swinging of the stream.

After a single glacial epoch the streams in all the hanging valleys would be flowing in such gorges and would, in time, bring their beds down to a grade accordant with that of the main stream. Suppose, now, a second glacial epoch should intervene. The chances are that the main valley would be deepened still further by ice erosion while the gorges in the tributary valleys would become more or less clogged with drift. On the withdrawal of this second ice sheet the gorge bottoms of the tributary valleys would be left hanging above the bottom of the recently deepened main valley.

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[1] Watkins Glen-Catatonk Folio, No. 169, U.S. Geol. Survey.

[2] G. K. Gilbert, "Boulder Pavement at Wilson, N.Y.," *Jour. Geol.*, VI (1898), 771–75.

Should a tributary gorge have been incompletely filled with drift, its stream would begin the task of clearing out the drift and of cutting a second gorge in the bottom of the earlier one. Should it happen, however, that the drift filling of a gorge was so complete that the stream on reoccupying its old valley and taking a consequent course found lower ground to one side, a new and independent gorge would be cut. Should the consequent course induced by the drift topography correspond in part with that of the old gorge and differ from it in part, the stream would cut a new gorge where it found itself out of the old channel, and merely clear out the old gorge where the two courses were in coincidence.

Parts of the old drift-filled gorge unoccupied by the stream would be preserved and would remain indefinitely as fossil gorges hanging above the level of the main valley bottom.

If an interval of deglaciation sufficiently long ensued, the tributary streams would again bring their beds down to grade. A third epoch of glaciation would bring about a repetition of events with the possible formation of still another gorge in the hanging valley bottom. The number of distinct gorges should, then, give at least the minimum number of glacial invasions which the region had suffered. It would not necessarily give the maximum, for during one or more of the intervals the stream might have merely re-excavated one of the older gorges.

The relative width of gorges cut during different intervals should, other things being equal, give a rough measure of the relative length of the interglacial intervals which they represent. A comparison of the width of the older gorges with that of the postglacial gorge should, in the same way, give a rough measure of the length of the interglacial interval as compared with postglacial time. This would be true, of course, only providing the older gorges were occupied by streams during only one interval.

The criterion outlined above for the determination of repeated ice invasions is considered to have advantages over others in that the possibility of minor halts and readvances of the glacier being interpreted as distinct glacial epochs is reduced to a minimum, for streams require time for the excavation of gorges. If an interglacial gorge is as large or larger than the postglacial gorge of the same stream, it is a fair inference that the interglacial interval bore a similar ratio to postglacial time. It would be necessary, however, to take account of possible different gradients of the streams and different climatic conditions during the intervals, but the effects of these could hardly lead to the confusion of true interglacial intervals with minor retreats of a fluctuating ice front.

The conditions outlined in the preceding paragraphs are realized very fully in the Finger Lake valleys. The main troughs, extending approximately in the direction of ice movement, were deeply scoured, while tributary valleys, suffering less erosion, were left hanging. The extent to which hanging valleys were developed has been so well presented in the writings of Tarr and others that it need not be dwelt upon here.

If the glacial period in this region was represented by more than one ice invasion, with corresponding intervals of deglaciation, we should expect to find, in at least some of the numerous tributary hanging valleys, old drift-filled gorges representing the work of interglacial streams. Such gorges are abundant, though their interglacial origin has not, in most cases, been fully demonstrated. They have been described by Matson[1] as occurring in the Buttermilk valley, and by Tarr, in the valleys of Watkins Glen, Fall Creek, Six Mile Creek, and others in the neighborhood (see references in later paragraphs).

In the autumn of 1909 the senior author discovered in the valley of Six Mile Creek phenomena which apparently had not been recognized before and which seem to have a distinct and important bearing on the problem of multiple glaciation. During the year 1910–11 Mr. Edwin A. Filmer, at the senior author's suggestion, undertook a detailed study of the lower Six Mile Creek valley. The results of this study were embodied in a paper now in manuscript form in the Cornell University Library. The facts brought to light by our investigation of the valley seem worthy of wider publicity than is possible for this manuscript. Hence the present joint paper has been prepared by the senior author, who has, however, made free use of Mr. Filmer's material and conclusions.

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[1] G. C. Matson, "A Contribution to the Study of the Interglacial Gorge Problem," *Jour. Geol.*, XII (1904), 133–51.

THE VALLEY OF SIX MILE CREEK AND ITS GORGES

The troughlike Cayuga Lake basin splits at Ithaca into two prominent prongs, the one carrying the Inlet stream from the southwest and the other occupied by Six Mile Creek, which enters from the southeast (see Fig. 1). Of the two, the Inlet valley is the deeper and the steeper walled and is the main prolongation of the lake basin. It continues with a gradual rise of the valley bottom for about 10 miles southwest of Ithaca and then, by a "through valley" connects southward with one of the tributaries of the Susquehanna. It is a typical glaciated trough. Tributary valleys along this

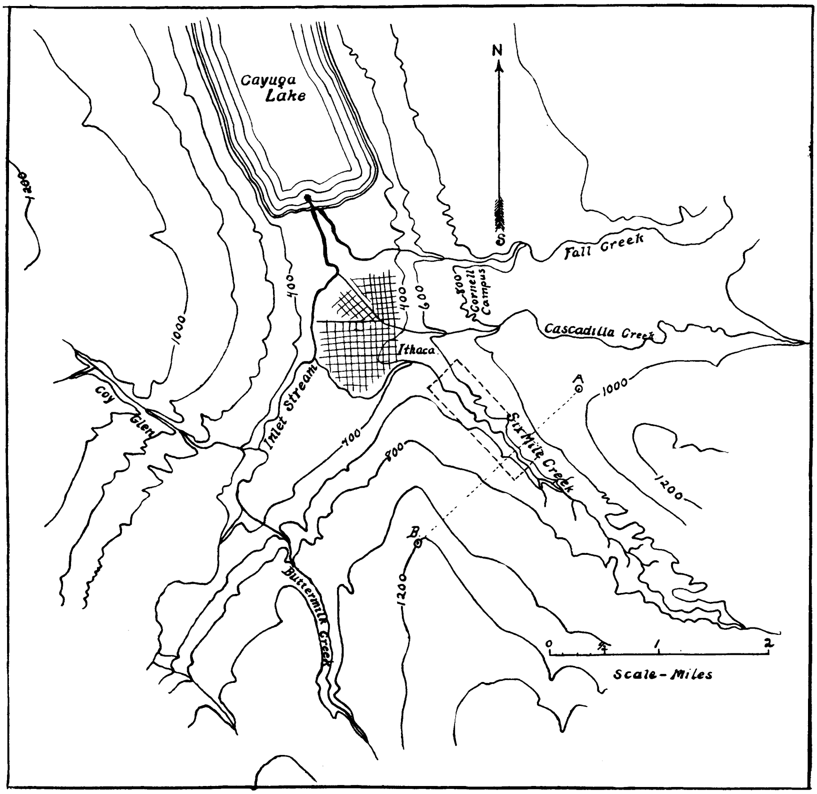

FIG. 1.—Map of the Ithaca region, showing the course of lower Six Mile Creek and its relation to the Cayuga valley and to other streams in the neighborhood. Area shown on Fig. 2 is inclosed by dotted lines.

trough are hanging and their streams enter through narrow rock gorges.

The Six Mile Creek prong is similar to the Inlet trough though it is not so deep and its sides are more flaring. The valley extends southeast from Ithaca in almost a straight line to Caroline Depot, about 7 miles to the southeast, where a southern prong of the valley connects by a low "through valley" past White Church and Willseyville with one of the headwater branches of the Susquehanna leading directly south.

That the valley of Six Mile Creek and this "through valley" were channels of vigorous ice motion during the glacial period is attested by (1) the character of the "through valley" at Willseyville, (2) the trunkated spurs and straight walls of the valley round White Church and Willseyville, (3) the distribution of the moraines in this latter valley and that of Six Mile Creek,[1] and finally by (4) the boat-shaped, typically glaciated cross-section of the lower Six Mile valley, recognized first by Simonds in 1877[2] and later by Tarr.[3] Simonds says (p. 51), referring to the Inlet and Six Mile Creek valleys:

> These deep, well-worn valleys are undoubtedly the result of glacial action. The mass of ice which filled the Cayuga Lake basin divided at its southern extremity. One part, the larger, flowed to the south, wearing down the Inlet valley, and the other traversed the Six Mile Creek valley, both of which were occupied by preglacial streams.

And Tarr (*op. cit.*, p. 20, first paragraph) says:

> . . . . Both Salmon and Six Mile Creek valleys hang at a much lower level than their neighbors (for example Fall, Cascadilla, and Buttermilk [Ten Mile]). I am now convinced that the interpretation of this discordance as opposed to the glacial erosion theory was incorrect and that these two valleys are really confirmatory of the glacial erosion theory. This change in view is the result of a recent study of the valley profiles and a mapping of the morainic deposits of the valleys in question. The latter show that these valleys were occupied by actively moving ice parallel to their axes while the neighboring higher hanging valleys were not. A study of the profiles shows that these discordant hanging valleys have the U-shape of glacial erosion and not the gorge

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[1] See Tarr, Watkins Glen-Catatonk Folio.

[2] Simonds, *American Naturalist*, XI (1877), 49–51.

[3] *Jour. Geol.*, XIV, No. 1 (1906), 20.

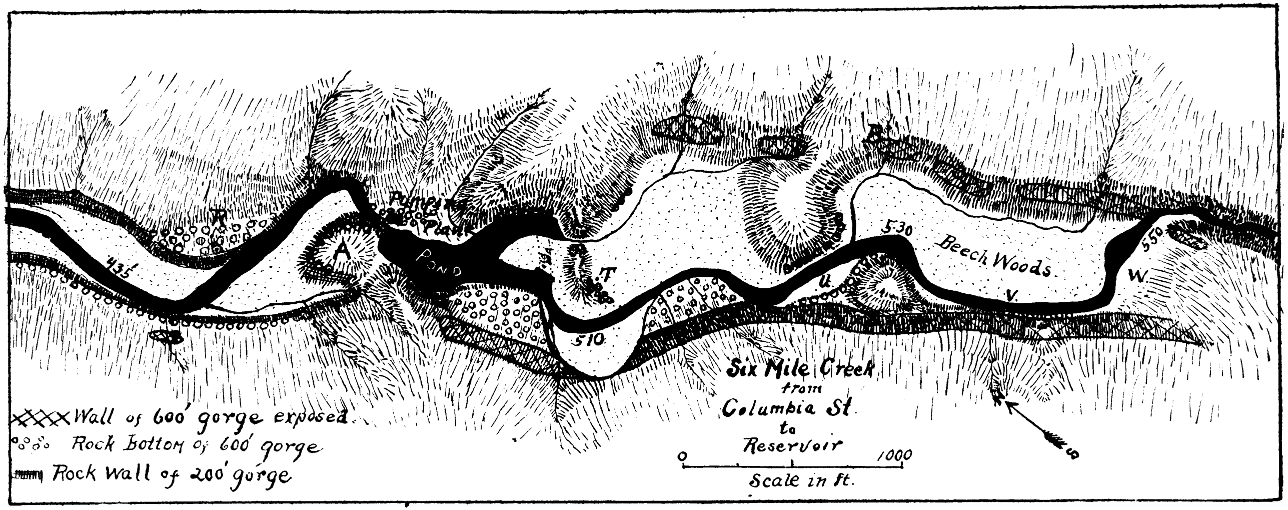
Wall of 600' gorge exposed
Rock bottom of 600' gorge
Rock Wall of 200' gorge
Six Mile Creek from Columbia St to Reservoir
0
1000
Scale in ft.
435
510
530
550
A
R
B
T
U
V
W
Pond
Pump Plant
Beech Woods

FIG. 2.—Map of a portion of the course of lower Six Mile Creek, showing the topography, the buried gorges, the outcrops of the rock walls and bottoms of the earlier gorges, and the elevations of the stream bed in different parts. The stream flows from right to left of the map. This map is reduced and somewhat modified from a map of the Six Mile Creek valley prepared by the city of Ithaca in connection with surveys for a water supply. Elevations shown represent height above sea-level and were taken from this map. They are approximately correct, but the writers cannot vouch for absolute accuracy.

shape of a rejuvenated valley, the only other explanation which seems a possible one for such discordance. It is believed, therefore, that while the Cayuga valley was profoundly deepened by ice erosion the Salmon and Six Mile Creek valleys were deepened moderately and the Fall, Cascadilla, Buttermilk, and other valleys practically not at all, since they were not occupied by ice freely moving along their axes.

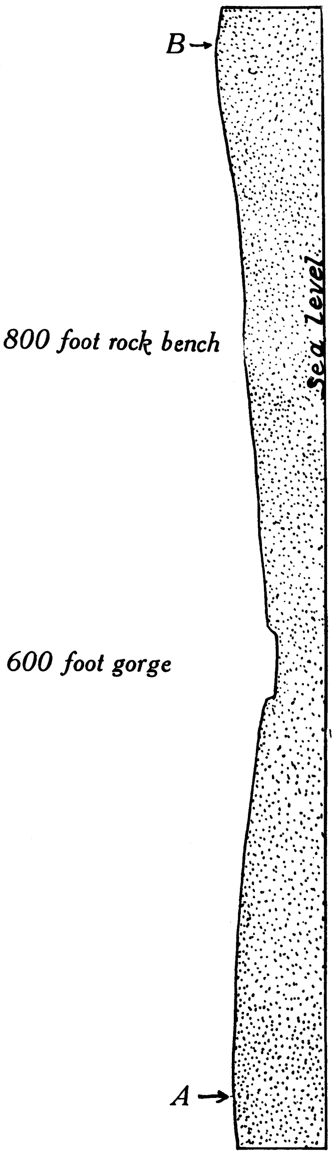

FIG. 3.—A profile across Six Mile Creek valley from *A* to *B* of Fig. 1, drawn to natural scale—vertical and horizontal scale the same (2,000 feet to one inch). This profile shows the relation of the 600-foot gorge to the broad valley of Six Mile Creek.

The evidence cited above, together with the foregoing quotations, makes clear the point which we especially desire to emphasize, namely, that the Six Mile Creek valley was occupied by actively moving ice and that it is hanging at a lower level than others near by because glacial erosion deepened its bottom, forming the U-trough so well shown in the profile (Fig. 3).

The rock bottom of the U-trough of lower Six Mile Creek valley is hanging at an elevation about 100 feet above the level of Cayuga Lake, and about 450 feet above the rock bottom of the Inlet valley at this point.

In the bottom of Six Mile Creek trough there is a series of three distinct gorges, which, according to our interpretation, are of different ages. Two are partly, and in places entirely, filled with glacial drift; the third is postglacial. The characteristics of these gorges and their relations to each other will appear from the following description taken in connection with the map (Fig. 2). There is an older gorge (hereafter referred to from its general width as the 600-foot gorge), 500–600 feet wide, of low gradient, in the bottom of which a second much narrower gorge, which we will call the 200-foot gorge, has been cut to a base-level some 100 feet lower than the other. Both of these gorges antedate the last ice invasion, being still filled by glacial deposits except where they have been cleared out by the postglacial stream.

A third, much younger, gorge (postglacial) is found in places where drift and lake delta deposits have so completely filled the earlier gorges that in re-excavating its valley the stream took a new course which, in this case, did not correspond with the former one. In cutting down in this new course the stream, encountering rock, developed the postglacial gorge.

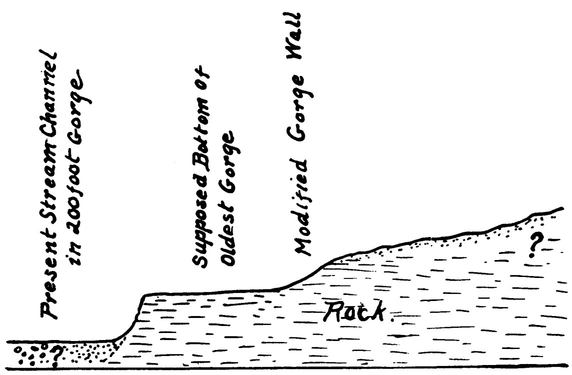
Present Stream Channel in 200 foot Gorge
Supposed Bottom of Oldest Gorge
Modified Gorge Wall
Rock
?
?

FIG. 4.—Sketch showing bottom and sides of gorge as it appears from upstream

The bottom and walls of the oldest, or 600-foot, gorge are exposed in numerous places for a distance of over a mile. The first evidence is seen just below the Ithaca waterworks pumping plant, where a rock bench, representing the old gorge bottom and east wall, shows in section where the postglacial stream has been undercutting its banks. The characteristics of this section as seen from upstream are indicated in the accompanying sketch (Fig. 4). A little farther upstream, just below the road, is an interesting section best illustrated on the map (Fig. 2). A rock island (*A* of Fig. 2) is found between the buried 200-foot gorge on the south and the recent postglacial gorge. The top of the rock in this island lies approximately at the level of the previously described rock bench across the stream just below. The rock bench and the rock island together are interpreted as the bottom of the oldest, or 600-foot, gorge. Proceeding upstream about one-quarter mile one comes to a portion of the valley where relations are very clearly shown (see map). Both walls of the old gorge are revealed and the bottom is seen along the southwestern edge and in two places near the middle of the gorge. Proceeding still farther upstream along the northeast bank, one may follow a small stream which enters the amphitheater from the east. For a few hundred feet the course is along a narrow valley excavated in drift. Then, suddenly, one comes upon a nearly perpendicular rock wall which the stream has encountered in its downcutting and over which it falls in a cascade. The rock wall is straight and disappears at both ends under drift. Following southeastward along the projected line of this rock wall, one crosses a hill of drift and soon comes down to the continuation of the wall on the other side (*B*, Fig. 2). Here it is fully exposed, perpendicular, and about 60 feet in height. At the northern end of the exposure the gorge wall is glaciated. The perpendicular cliff is smoothed and striated in true glacial fashion (Fig. 5). From here the gorge wall may be traced almost continuously upstream to the postglacial gorge just below the reservoir, where, after being crossed by the main stream, it disappears under drift (near *W*).

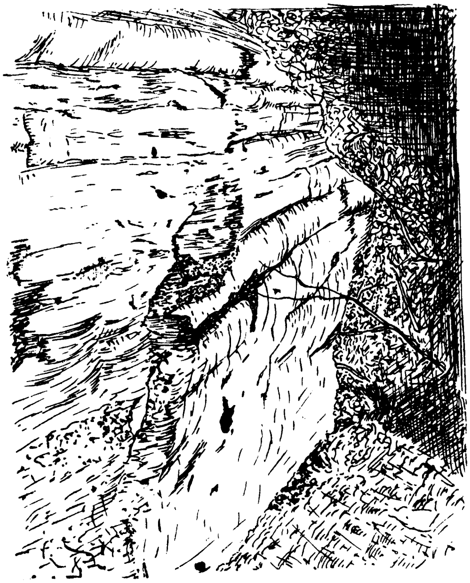

FIG. 5.—The glaciated rock wall of the 600-foot gorge disappearing under drift. From a photograph.

The southwestern wall may be traced with practical continuity all the way. It is, in general, less steep than the northeastern wall.

A steep slope in the place of a vertical cliff is the rule. This southwestern wall also disappears under drift just below the reservoir.

The large amphitheater (just outside the limits of Fig. 2) in which the reservoir lies represents the old gorge again occupied by the stream and locally widened to an unusual extent. Here the gorge walls on the south are steep, but not vertical. On the northeast side the wall appears in several places where small side streams have cut through the overlying drift. It is generally a perpendicular cliff.

The bottom of the old 600-foot gorge, as exposed in a number of places, rises upstream at a rate slightly less than that of the present stream. As a result, the bottom, which appears some 6 feet above the stream at the pumping plant, reaches stream level at the reservoir and lies below it farther up. Partly for this reason the old gorge, in the upper part, becomes more and more indistinct. Its general width, taking the mile of its course just described, is from 500 to 700 feet at the bottom and perhaps 100 feet more than this at the top, for the walls are not everywhere perpendicular. Its relation to the broader glacial trough of Six Mile Creek valley is well shown in the accompanying cross-section (Fig. 3), drawn to a vertical and horizontal scale of 2,000 feet to the inch. The profile makes evident the broad, U-shaped valley with the sharply cut gorge in its bottom. This gorge was probably nearly filled by drift during the various glacial epochs since its formation. In two cases—at the reservoir and south of Green Tree Falls—it is still drift-filled to the top; elsewhere the stream has cleared out a good share of the drift.

In two places on the gorge walls glacial striae have been found; one has already been mentioned, the other is at the eastern edge of the pond, just above the pumping plant. The striations show clearly that the gorge has been covered by ice since its formation, but it seems equally clear from the sharpness of the old gorge walls in most places that the action of this ice was weak and did not materially modify the form of the gorge except at the lower end and where the exposure was particularly favorable. It would seem, therefore, that the gorge must have been cut subsequent to the formation of the broad U-trough of Six Mile Creek valley, in the bottom of which the gorge lies. Otherwise it probably would have been obliterated by the deep glacial erosion which produced the U-trough.

The second gorge is exposed only below the pumping plant. It is now occupied by the stream all the way from a point a few hundred feet below the pumping plant to the Cayuga Lake delta. Its bottom is nowhere to be seen, since it lies below the level of the present stream. Whether or not it goes below the present base level of Cayuga Lake has not been determined. The fact that the stream is not flowing on a rock bed is not necessarily proof of its having been cut to a lower base level, for it may be that we fail to find rock in the bed of the stream because of the aggradation of the stream bed in connection with the formation of the alluvial fan on which the city of Ithaca stands.

At the Stewart Avenue bridge the gorge is 200 feet wide at the top and has nearly perpendicular walls. Traced upstream, it disappears under drift on the south side of the rock island previously described (*A* of Fig. 2), while the stream lies to the northeast in a postglacial gorge. At the point of disappearance the old gorge has a measured width, from rock to rock of the valley sides, of 125 feet at the bottom. It is nowhere seen farther upstream. It is to be presumed that it lies buried somewhere within the bottom of the older gorge. If so, it must pass under the eastern arm of the pond, for rock exposures preclude its presence elsewhere.

The gorges of the third series are postglacial. They occur where the stream, in cutting down through the later deposits of drift, happened to find itself outside its former gorge. In Six Mile Creek there are three postglacial gorge sections—one just below the pumping plant, another just below the reservoir, and the third just above Green Tree Falls. This latter is being utilized as the site of a second dam for a reservoir for the Ithaca water supply. In the case of the lower of these, at the pumping plant, the diversion of the stream was probably due not so much to filling of the older gorge by glacial till as to the delta deposits built by the stream into Cayuga Lake when it stood at one of its higher levels. A section at the upper end of the rock island by the pumping plant shows till at the base overlain by finely laminated lake clays about 4 feet in thickness, on which lies an undetermined thickness of delta gravel. This delta deposit is well shown in a cut on the east side of the road, where it was used for gravel. It lies at the general level of the lowest large deltas of Coy Glen and Butternut Creek. There is some evidence, not yet fully worked out, which points to similar deposits as the cause of the diversion of the stream into the two other postglacial gorges farther upstream.

The postglacial gorges are narrow, with walls for the most part vertical rock cliffs. The lower and upper of these gorges still possess waterfalls and cascades. In every case they are distinctly smaller than even the second of the older gorges.

INTERPRETATION

The interpretation put upon the series of gorges in Six Mile Creek is that they were formed by the stream during interglacial intervals. The sequence of events is interpreted as follows:

1. *Preglacial time.*—The stream probably flowed in a broad, mature valley, tributary to the Cayuga Lake trough. The bottom of this valley may have lain at the level of the pronounced rock bench which is clearly marked along the south side of the valley between the 800- and the 1,000-foot contours. This bench is well shown on the topographic map, and is brought out clearly in the accompanying profile (Fig. 3).

2. *First glacial epoch.*—The Cayuga trough, extending parallel with the direction of ice movement, was greatly deepened by ice erosion while at the same time Six Mile Creek valley was deepened considerably and given the flaring U-form typical of glacial erosion. The deepening of the Cayuga trough exceeded that of the Six Mile Creek trough, leaving the latter hanging.

3. *First interglacial interval.*—During this interval Six Mile Creek cut a gorge in the bottom of its hanging valley. That gorge is the oldest, or 600-foot, gorge, described above. The interglacial interval must have been long, for the gorge was cut to an even gradient throughout the whole extent now visible and was also widened very considerably. As we have pointed out before, the gradient of the stream that developed during this interglacial interval was flatter than that of the present stream. An attempt was made, by taking several points as definitely located as possible

on the rock bottom of the old gorge, to plot its profile to scale (see Fig. 6). Points were taken at intervals through a distance of over a mile along the gorge. It was found that, when these points were plotted, the line connecting the first and last passed very close to all the others. This would show that the gorge bottom was well graded. When this profile of the gorge is projected out over the Cayuga valley it is found that at the edge of the Cayuga trough the bottom of the gorge must have been hanging 80 feet above the present lake level. Projecting this line still farther to the axis of the trough, we find it 28 feet above the present lake level. This would indicate that during the first interglacial interval the base level in the main valley stood approximately 80 feet above the present lake level. This base may have been a stream in the main valley or it may have been a lake similar to the one now occupying the basin. We shall discuss later the evidence bearing on this point.

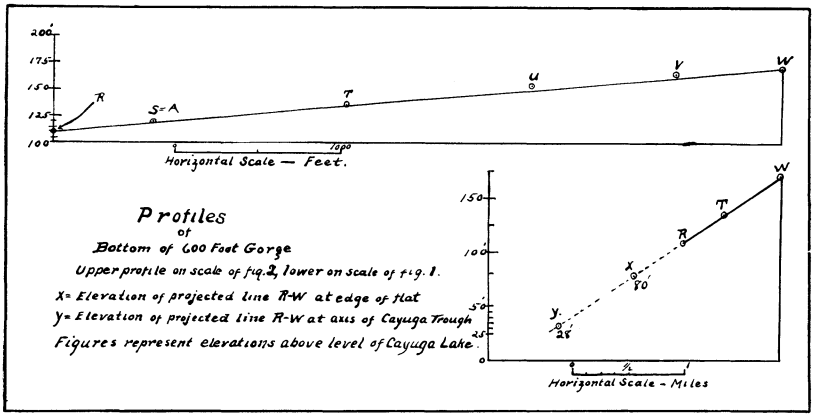

FIG. 6.—Profiles of the rock bottom of the 600-foot gorge. Elevations, taken from the Ithaca water survey map, represent height above Cayuga Lake level. For height above sea add 381 feet.

4. *Second glacial epoch.*—A second glacial epoch followed and so lowered the base level in the main valley that the tributary stream again found itself hanging. The ice, during this glacial invasion, seems to have considerably modified the lower part of the 600-foot gorge. The sides and bottom were smoothed and striated and the walls of the gorge at the lower end appear to have been much eroded

and partly destroyed. These gorge walls become practically unrecognizable below the rock island. Without a doubt some of this erosion was done by the later, Wisconsin, ice sheet, but it is thought that the greater part was earlier. The reasons for this belief will be stated in a later paragraph.

5. *Second interglacial interval.*—At the close of the second glacial epoch Six Mile Creek, again left hanging, began cutting another gorge—the 200-foot gorge through which the stream now flows from the rock island to the alluvial flats of the Cayuga valley. The base level of this gorge must have been as low as the present lake level, for rock is nowhere exposed in the stream bed. How much below the present lake level the interglacial base may have been we have no means of knowing. The time interval represented by this gorge must have been much shorter than that during which the older, 600-foot, gorge was cut, for, as has been stated before, the width of the gorge is not much more than one-third that of the older gorge. Judging from the size of the gorge, however, the time must have been much longer than the interval since the last glacial epoch, for the gorge was cut back at an approximately even grade for a distance of two-thirds of a mile at least—how much farther we have no means of knowing, for it is buried under drift. Postglacial streams of equal size have succeeded, at best, in grading their gorges only a few hundred feet back from the Cayuga valley trough. In fact, most of them come tumbling down over the rocks of the hillsides through gorges which are merely notches in comparison with the interglacial gorges.

6. *The third glacial epoch, Late Wisconsin.*—This ice invasion put an end to the gorge-cutting. It filled or partly filled the older gorge with drift and at its close delta deposits further clogged the gorges until, as the lakes were lowered, the stream found its old channel so completely blocked in places that it must seek lower ground to one side. This determined the stream's course.

The ice of the Wisconsin epoch seems to have done little toward modifying the form of the second gorge. Its walls are still steep and angular and on them we know of no glacial striations having been found. It is the fresh appearance of this second gorge, as compared with the glacially eroded lower end of the 600-foot gorge, which led us to believe that the Wisconsin ice had played but a small part in the widening and modification of the 600-foot gorge. It seems to be still an open question whether the ice of the *latest* Wisconsin epoch ever extended beyond the belt of strong terminal moraines just south of Ithaca.[1] If it did not, we should expect only feeble erosive action from the Wisconsin ice in the Ithaca region. It is interesting to note, in this connection, that Tarr, in his report on the Watkins Glen-Catatonk Folio, emphasizes the slight erosion by Wisconsin ice.

7. *Postglacial interval.*—This has been marked, in the case of Six Mile Creek valley, by the partial re-excavation of the older gorges and by the cutting of postglacial gorges in places where the postglacial stream found itself outside its former course. The postglacial seems to have been the shortest of the intervals of deglaciation. The gorges are relatively small and show much less stream erosion than the others. In spite of the fact that climatic differences may have influenced the rate of gorge-cutting, it seems legitimate to judge, roughly, the length of an interglacial interval by the size of its gorges.

ALTERNATIVE HYPOTHESES

Before the interpretation outlined above can be considered established, certain questions call for consideration. The first of these is whether the observed relation of the 200-foot gorge to the 600-foot gorge—that is, cut in its bottom—necessitates for its explanation the intervention of a glacial epoch; the second is whether the 600-foot gorge may not be a product of preglacial rejuvenation.

In answer to the first of these questions it may be said that the whole problem resolves itself into a search for an adequate reason why the stream, after cutting the 600-foot gorge to a low gradient—evidently to its local base level—and widening it considerably, should suddenly have renewed its downcutting sufficiently to have formed the 200-foot gorge in the bottom of the older one. Several possible explanations present themselves: (*a*) there may have been a lake in the main valley whose level was suddenly lowered; (*b*) the main valley may have been occupied by a stream which in some way, perhaps by uplift, was suddenly rejuvenated; (*c*) a glacial invasion may have altered the base level in the main valley. In regard to these possible explanations, we believe it not only possible, but very probable that a lake, similar to the present Cayuga, existed in the valley previous to the last ice invasion. It is conceivable, also, that such a lake might be drained comparatively suddenly. For instance, a hard rock stratum might be so disposed as to form a barrier which would yield rather suddenly and expose weaker rocks beneath. It is evident, therefore, that we cannot at once dispose of hypothesis (*a*). On the other hand, we have in Six Mile Creek alone no means of proving that a river in the main valley may not have been suddenly rejuvenated. It will be apparent, however, that if such a trunk river, by its rejuvenation, led to the formation of a gorge in Six Mile Creek valley, it should, in a similar manner, have led to the formaton of similar gorges, corresponding to the 200-foot gorge of Six Mile Creek, in all the other tributaries. We should expect to find, then, that the wide buried gorge of Buttermilk Creek, which apparently corresponds to our 600-foot gorge, should have a narrower gorge, corresponding to our 200-foot gorge, sunk in its bottom. Such is not the case, however. We must conclude from this, we believe, that hypotheses (*a*) and (*b*) are both untenable, for the argument stated above would apply equally well in the case of a lake whose level was suddenly lowered. The third hypothesis suggested—the lowering of the base level of the tributaries by the intervention of a period of glacial erosion—does not meet with this objection, for it might well happen that the Six Mile stream, after the disappearance of the ice, would find itself still in its old channel, while the Buttermilk stream, happening to find its old channel blocked by drift or delta deposits, cut a new gorge elsewhere, as, in fact, it has done.

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[1] Chamberlin, in his report on the "Terminal Moraines of the Second Glacial Epoch" in the *Third Annual Report of the U.S. Geol. Survey*, states, as a possibility, that the moraine in question represents the limit of Wisconsin ice movement. It seems to the writer that this possibility has never been satisfactorily set aside.

A careful study of the buried gorges of Butternut Creek, Newfield Creek, and others should be made in order to settle the question beyond possibility of dispute.[1]

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[1] In this connection it may not be out of place to call the attention of any whose lot it may be to make a further study of these buried gorges to a remarkably fine buried

To return to a consideration of the second question, namely, whether the 600-foot gorge may not be a product of preglacial rejuvenation, we have seen that lower Six Mile Creek valley was profoundly deepened and modified by ice erosion and that it was given the broad, flaring U-form of a typical glacial trough. The 600-foot gorge now lies in the bottom of this trough and still retains perpendicular or nearly perpendicular rock walls throughout much of its extent. If this gorge was formed by a preglacial stream it must have survived the deep scouring which lowered the bottom of the valley to an extent of some 200 feet or more and modified its form to that of a typical U-trough. It is hard to believe that such a gorge would not have been widened by the ice and made a part of the U-trough had it been in existence while the erosion was in progress. At least the sharpness of the gorge walls would have been destroyed. It is true that, on the southwest wall of the gorge, this sharpness has been to some extent destroyed, but this is probably the result of erosion by the ice of some of the later periods. The northeast wall is still sharp.

A further point which may have a bearing on this problem is the fact that in the valley of Fall Creek there are drift-filled gorges, as, for instance, those just north of the Triphammer Bridge, whose bottoms are nearly 200 feet above that of the 600-foot gorge in the Six Mile Creek valley. Certainly these gorges cannot belong to the same cycle as the 600-foot gorge, for both seem well graded, yet their base levels are so different. If either is preglacial it must be the higher one. Buried gorges at levels higher than our 600-foot gorge are to be found in several of the valleys of the region besides that of Fall Creek. On detailed study, with careful leveling, it may appear that even the 600-foot gorge of Six Mile Creek belongs to a

gorge in the valley of a small stream which enters Cayuga Lake from the east at Shurger Point. In following up the gorge of this stream one soon encounters a series of cascades and falls aggregating perhaps 75 feet in height. Above these cascades is a gorge 100 feet, more or less, in width at the bottom, with rock walls, and a remarkably even, low-gradient rock floor. The gorge, with these characteristics, continues upstream for half a mile to a point just below the trolley track (one mile from the lake), where it suddenly ends, the rock walls disappearing under drift, and the stream tumbling in over a fine fall 60–80 feet in height. The bottom of the upper section of this gorge has a low gradient and hangs at a level somewhere between 60 and 100 feet above that of Cayuga Lake.

comparatively late interglacial interval, and that some of these higher gorges represent still earlier intervals, thus still further increasing the complexity of the glacial record.

LITERATURE

The interpretation of these gorges which we have presented is not, in all respects, new. A brief summary of the literature pertaining to Six Mile Creek and its gorges will indicate the status of the problem previous to the recent investigations.

Probably the first mention of the drift-filled gorges was made by Simonds in 1877,[1] who says: "The valley of Six Mile Creek furnishes some special examples of the drift phenomena. In several places its old channel has been completely choked up with masses of morainic débris, about which the present stream has been obliged to cut its way through deep canyons." This reference is interesting, though it contains nothing bearing directly on the problem in hand.

In the *Physical Geography of New York State* (New York: Macmillan Co.), published in 1902, Tarr, under the heading "Interglacial(?) Gorges" (pp. 178–79), calls attention to "numerous gorges which are broader than the postglacial valleys and partially obscured by glacial till, showing that they were formed either during preglacial or interglacial times," and mentions Six Mile Creek as an especially good example. The problem which has ever since been recurring, and, in fact, still calls for discussion, is there clearly stated: "Were the gorges [of central and western New York] due to the interglacial conditions or to an uplift in preglacial times?"

In a paper on "Hanging Valleys in the Finger Lake Region of Central New York"[2] Tarr discusses the Six Mile Creek gorges at some length. He points out the fact that practically all the valleys tributary to the Finger Lakes possess gorges "which antedate the last advance of the ice" and that in the case of Six Mile Creek

> the stream alternately enters the buried gorge, forming broad amphitheaters, and where it for a short time leaves the earlier gorge, crosses spurs of rock in

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[1] *American Naturalist*, XI (1877), 49–51.

[2] *American Geologist*, XXXIII (May, 1904), 271–91.

> narrow, postglacial gorges. . . . . A third condition is where a stream enters the earlier gorge, clears out part or all of its drift filling, and follows it across the steepened slope to the main valley. This is certainly the case in lower Six Mile Creek.

It should be noted that in this reference to Six Mile Creek Tarr makes no distinction between the gorge characterized by the "broad amphitheaters" mentioned above (our 600-foot gorge) and the gorge of "lower Six Mile Creek," which the stream follows to Cayuga valley (our second, or 200-foot, gorge).

A following paragraph (p. 281) is especially significant in connection with the facts brought out by our recent study. We quote in full:

> This evidence establishes a third point regarding the drainage history of Seneca and Cayuga valleys, namely, that there is an almost, if not absolutely, uniform condition of gorges in the bottoms of the mature hanging tributary valleys; that these gorges, being drift-filled, antedate the last ice advance; that they are broader and deeper, hence required longer time to form than the postglacial gorges; and that, where they enter the main valleys, their rock bottoms are above lake level. They therefore resemble hanging valleys, since their bottoms are in some cases, as Taughannock, about 400 feet above the main valley bottom one-half mile distant. Since we have no data proving what their bottom slope actually is, though it seems evident that their slope is very steep, and possibly great enough to carry them down to the main valley axis, it may not be proper to consider them hanging valleys. If the interpretation of hanging valleys is warranted, which I doubt, then the tributary valleys to Seneca and Cayuga Lakes are double hanging valleys—an upper mature hanging valley and a lower hanging gorge valley.

In the case of Six Mile Creek at least we now have the data proving the actual bottom slope (Fig. 6) and it appears that the slope is, in reality, comparatively gentle, and that the double hanging valleys of which Tarr speaks are, in fact, present.

In another paragraph in the same paper (p. 284) the results of our recent study are foreshadowed in the following words:

> A modification of the glacial erosion theory has been advanced during the progress of the investigation of the problem and is still being considered. It is as follows: During its first advance the ice deeply eroded the valleys; during interglacial conditions the older valleys were cut; with return of glaciation the valleys were deepened still further. During as many glaciations as this region experienced this process was continued. On this basis the older gorges are interglacial; their cause is the lowering of their base level by the overdeepening of the valleys to which they were tributary. Since facts sufficient to establish

or to overthrow this explanation are not yet at hand it must stand at present merely as a working hypothesis.

The question of the explanation of the buried gorges by regional rejuvenation is then raised (p. 290). Two sentences in connection with this are quoted:

> Distinct progress toward solution might be made if it were possible to establish the grades of the buried gorges. If they can be shown to have such steep grades as to carry them down to the main valley bottoms the theory of rejuvenation will be greatly strengthened.

In this connection we again call attention to Fig. 6, showing the projected grade of the rock bottom of the oldest of the buried gorges of Six Mile Creek, which profile, it would seem, does not tend to strengthen the rejuvenation theory.

As late as 1906 we find the following in regard to the gorges of the Finger Lake valleys:[1]

> There are some facts which indicate possible greater complexity of ice erosion, for in some of the valleys there is apparently more than one buried gorge; but the evidence on this point is not as yet convincing, and for the present we can point with certainty to no greater complexity than that of two periods, one the Wisconsin, the other of some one of the earlier ice advances, with which the work of the glacial geologists of the Mississippi Valley have made us familiar.

Tarr's latest published conclusions in regard to these buried gorges may be found in the Watkins Glen–Catatonk Folio of the United States Geological Survey,' 1909. He concludes that evidence of a pre-Wisconsin period of ice erosion "is afforded by the presence of hanging gorges, partly buried in Wisconsin deposits. . . . . These are evidently interglacial gorges cut in the bottoms of hanging valleys that were left hanging by overdeepening of the main troughs through ice scouring" (p. 117, field edition); and again, p. 224: "We have conclusive evidence here [referring to the buried gorges] of only two advances, but there may have been more."

Matson (*op. cit.*) at an earlier date had described buried gorges in the valley of Buttermilk Creek, near Ithaca, which led him to the conclusion that in that valley there exists a "series of complex gorges which are considered interglacial. The minimum number of epochs of deglaciation is two; the maximum number, four. . . . ."

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[1] R. S. Tarr, "Watkins Glen and Other Gorges of the Finger Lake Region of Central New York," *Pop. Sci. Mo.* (May, 1906), 387–97.

It will be evident from the foregoing summary of the literature that more than one set of buried gorges has been recognized, or at least suspected. The problems still left unsolved were: (1) the details of these gorges, and the number present in different valleys; (2) the gradient of the gorge bottoms; (3) the possibility of the explanation of one of the buried gorges by preglacial rejuvenation.

BROADER BEARINGS OF THE PROBLEM

The buried gorge phenomena of Six Mile Creek do not stand isolated. Similar phenomena in many other valleys of the region have been recorded.

If our interpretation is correct they all form a definite part of the sequence of events connected with the glacial epochs. Some valleys should show several gorges; some, perhaps, in cases where the stream happened to find the same channel each time, should show only one. The phenomena in Six Mile Creek valley point to at least three glacial epochs separated by periods of time longer than that since the last epoch. Other valleys may show an even more complete record. Buttermilk valley shows a more complex series than Six Mile, and Butternut Creek has a splendid series of old gorges, very little studied as yet.

As the study of these gorges progresses it should be possible to settle many points now in question. For instance: the 600-foot gorge of Six Mile Creek was cut to a base level approximately 80 feet above present lake level. The largest gorge of Buttermilk was cut to approximately the same base. The base of the largest gorge in Butternut Creek lies at approximately the same level—perhaps somewhat higher. By careful leveling it should be possible to determine with close approximation the base level to which each of these gorges was cut. It may be possible in this way to determine whether a lake (horizontal base level) or a river (inclined base level) occupied the main valley at the time of the cutting of the gorges. The Finger Lake valleys and their tributaries afford abundant evidence which must be studied carefully before a final decision as to the full complexity of the glacial period in central New York can be made.